

A new parameterization of ice cloud optical properties based on a two- habit ice particle model

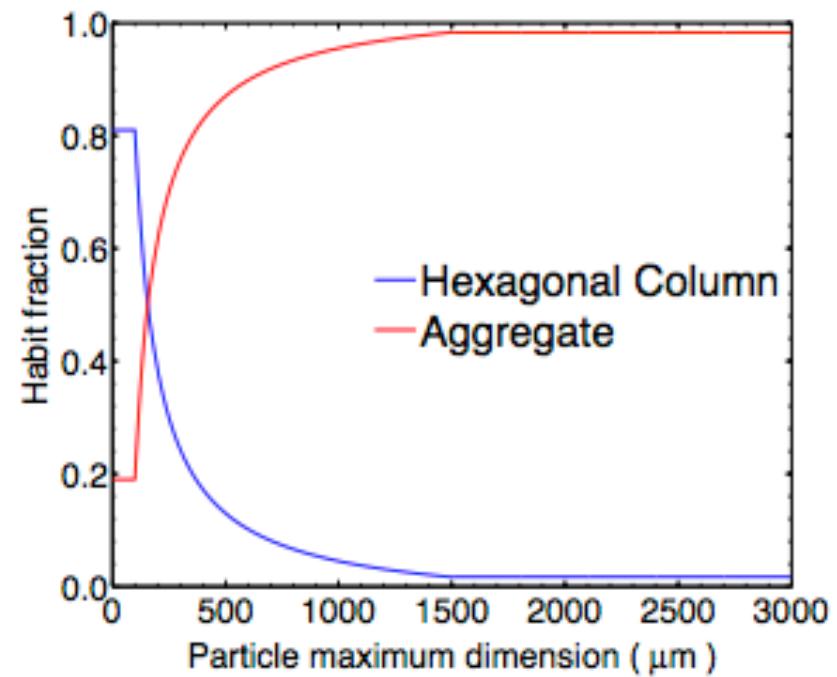
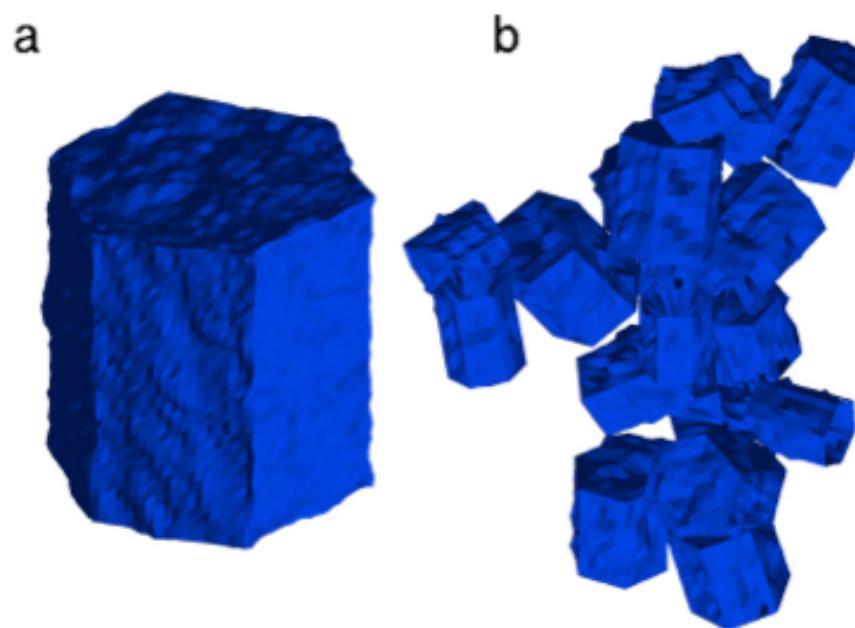
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Patrick Minnis,² Norman Loeb,² Seiji Kato²

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MOTIVATION

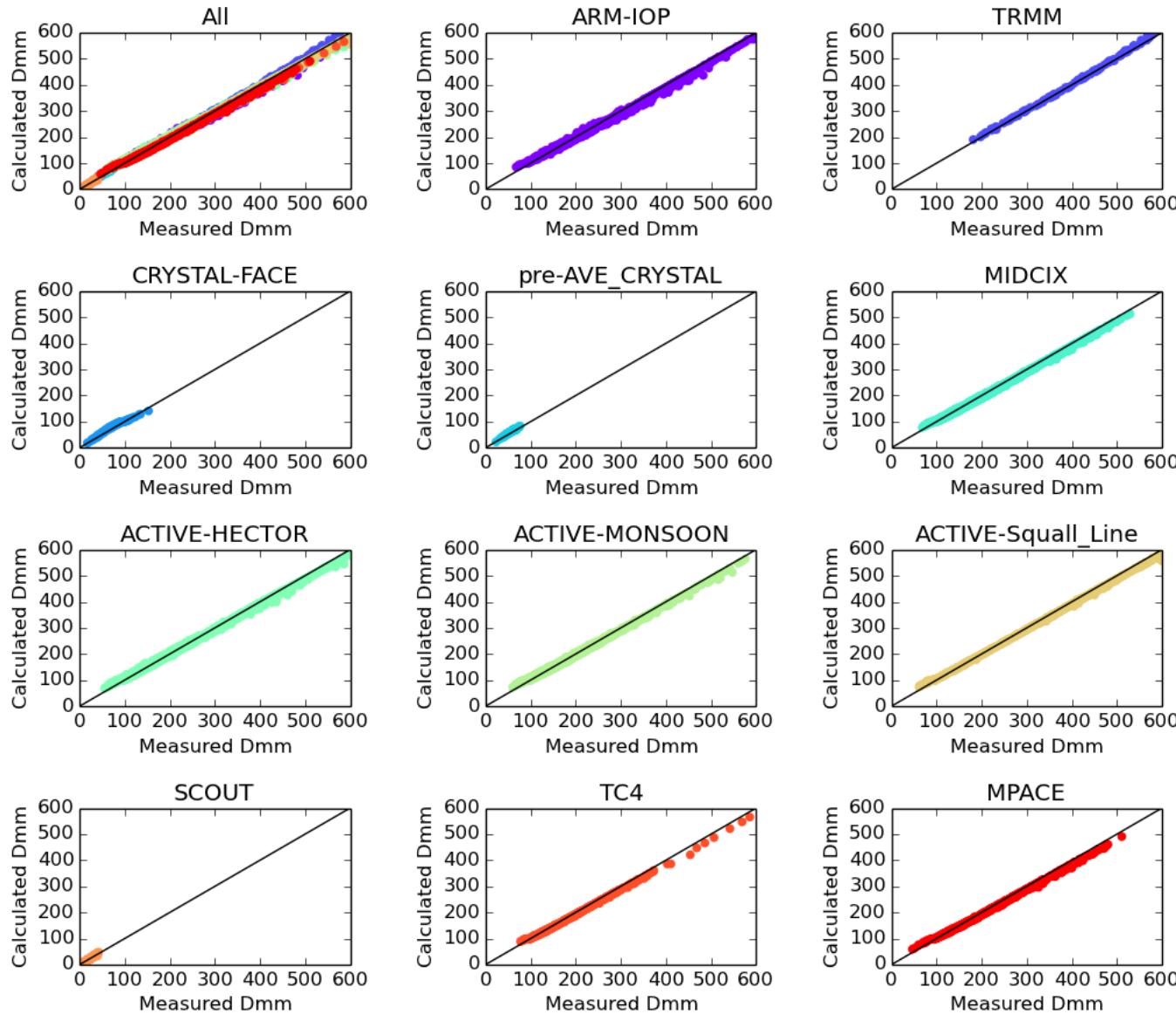
- Most current ice crystal models used in cloud retrievals and in RTMs are not consistent across all wavelengths and optics
 - cloud optical depths retrieved using VIS channels are ~half of COD for IR channels, use single column model (SHM)
 - polarization patterns do not match
 - needs to match mass to link hydro and radiative cycles
- A two-habit model (THM) has been provided to the Cloud Working Group for use in future CERES Editions
 - currently under evaluation
- If used by CERES, the Fu-Liou code will need to accommodate the new model across the SW and LW spectral bands
 - parameterization across all wavelengths developed, needs testing

Two-habit ice particle model (THM)

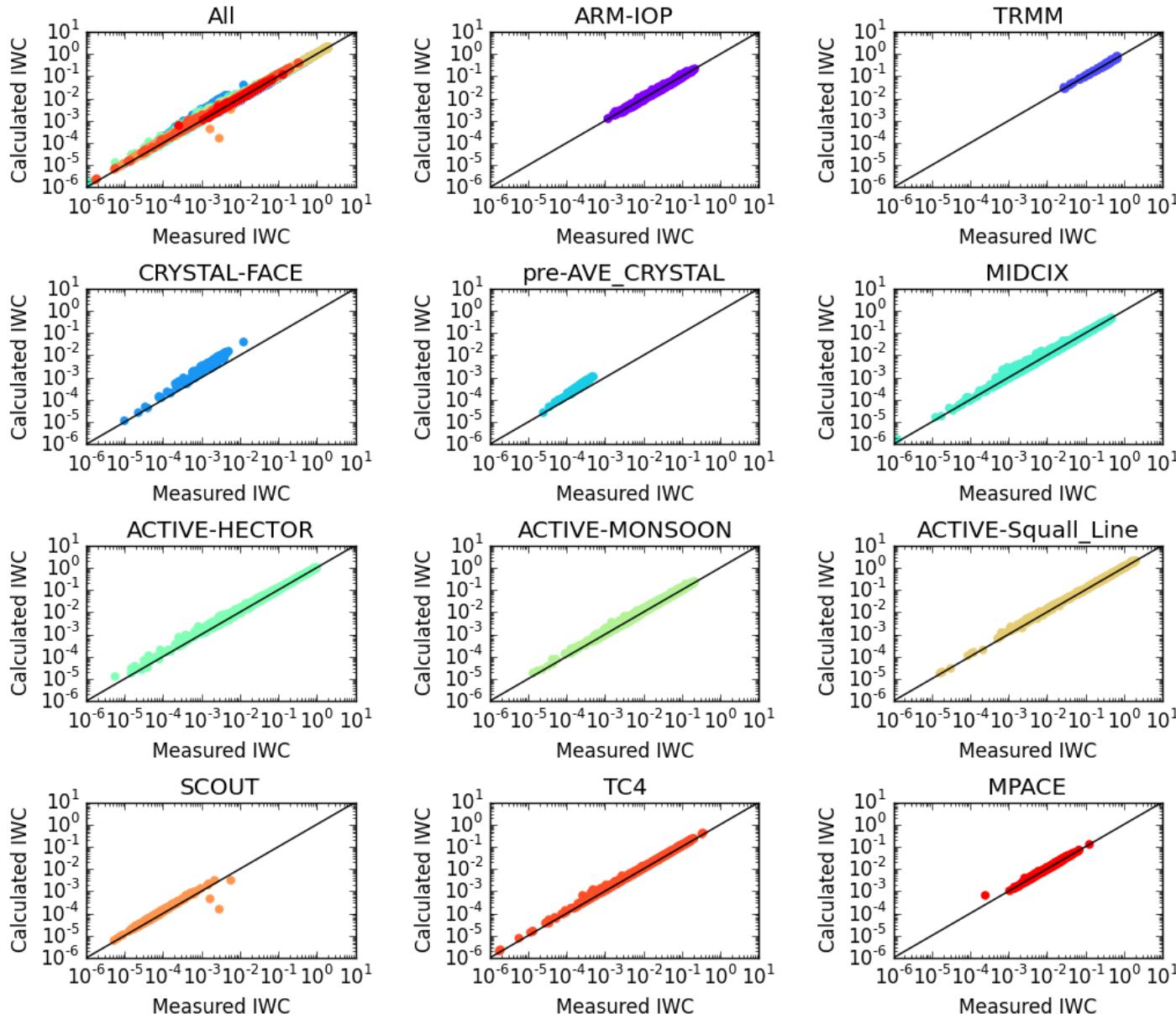


- (a) single hexagonal column with an aspect ratio of unity;
- (b) hexagonal aggregate with 20 solid or hollow columns.

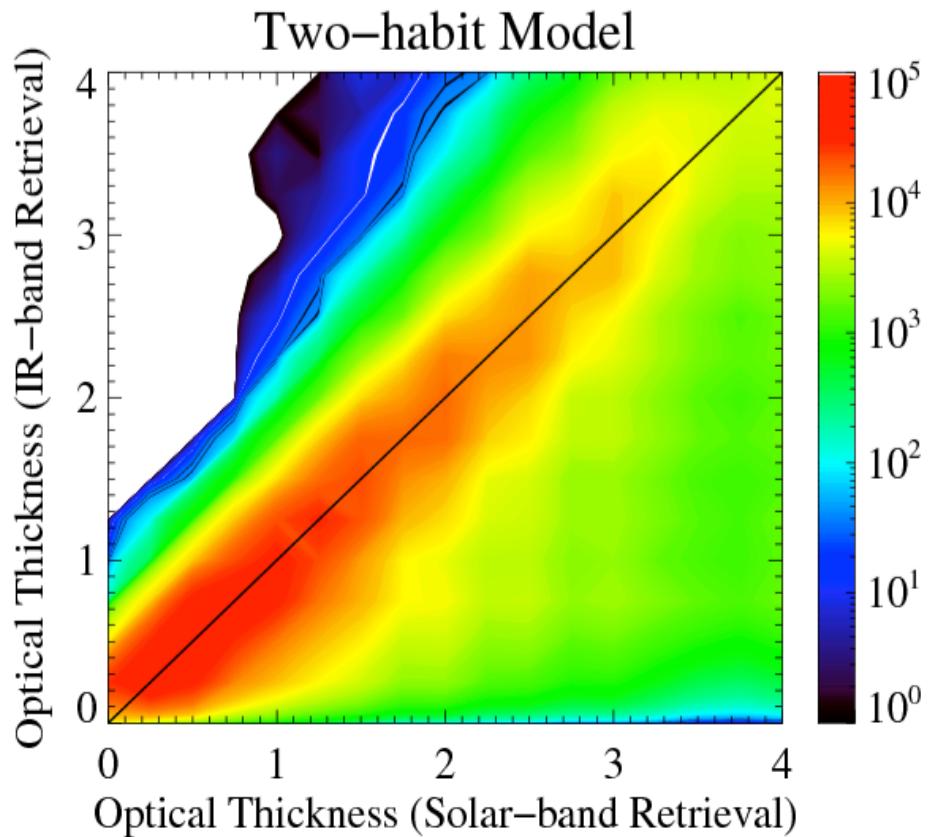
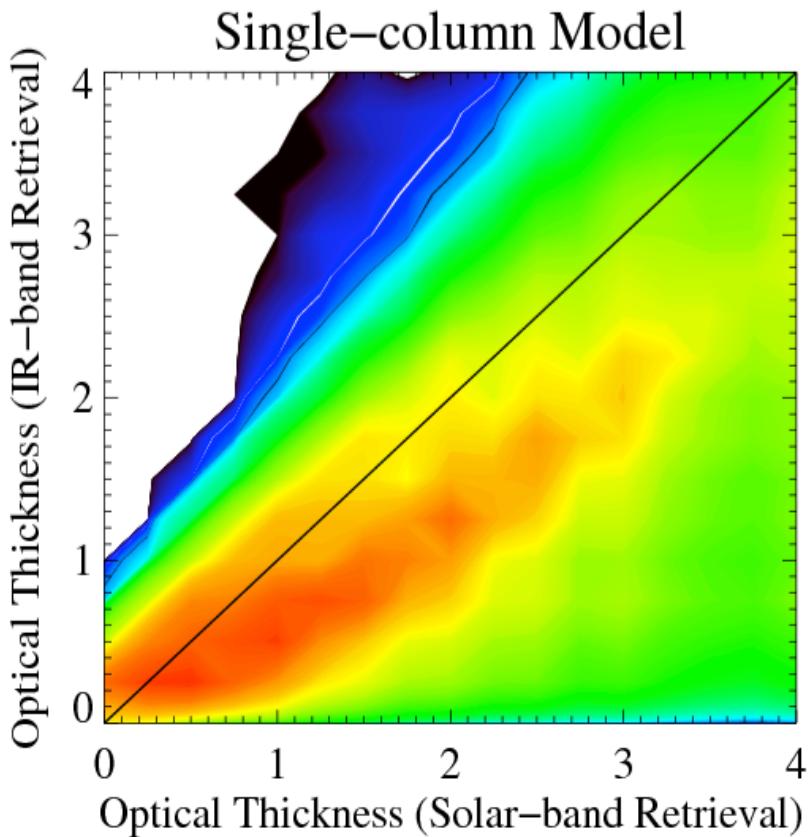
Median Mass Diameter (D_{mm}) : THM vs. Measurements



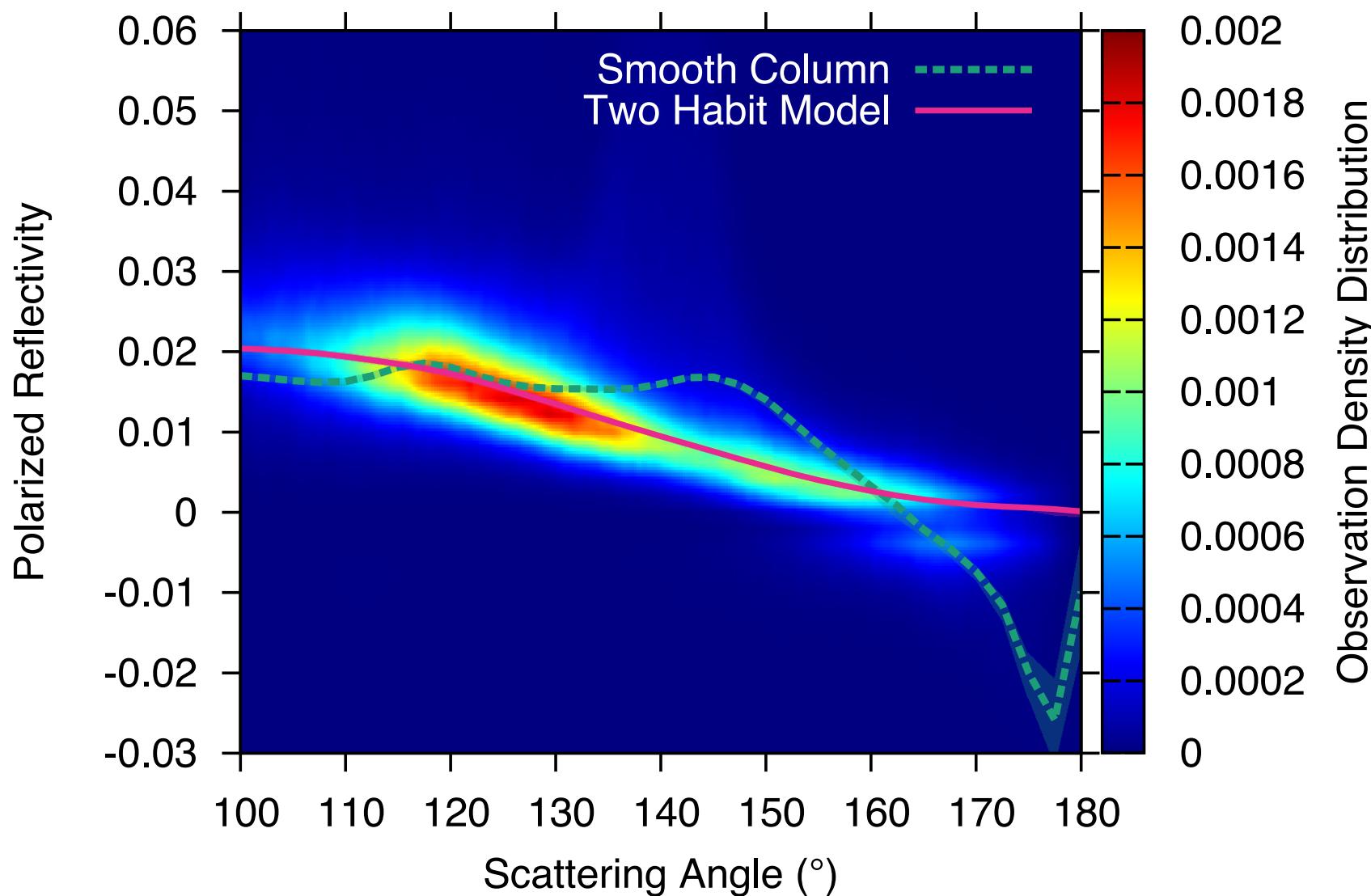
Ice Water Content (IWC): THM vs. measurements



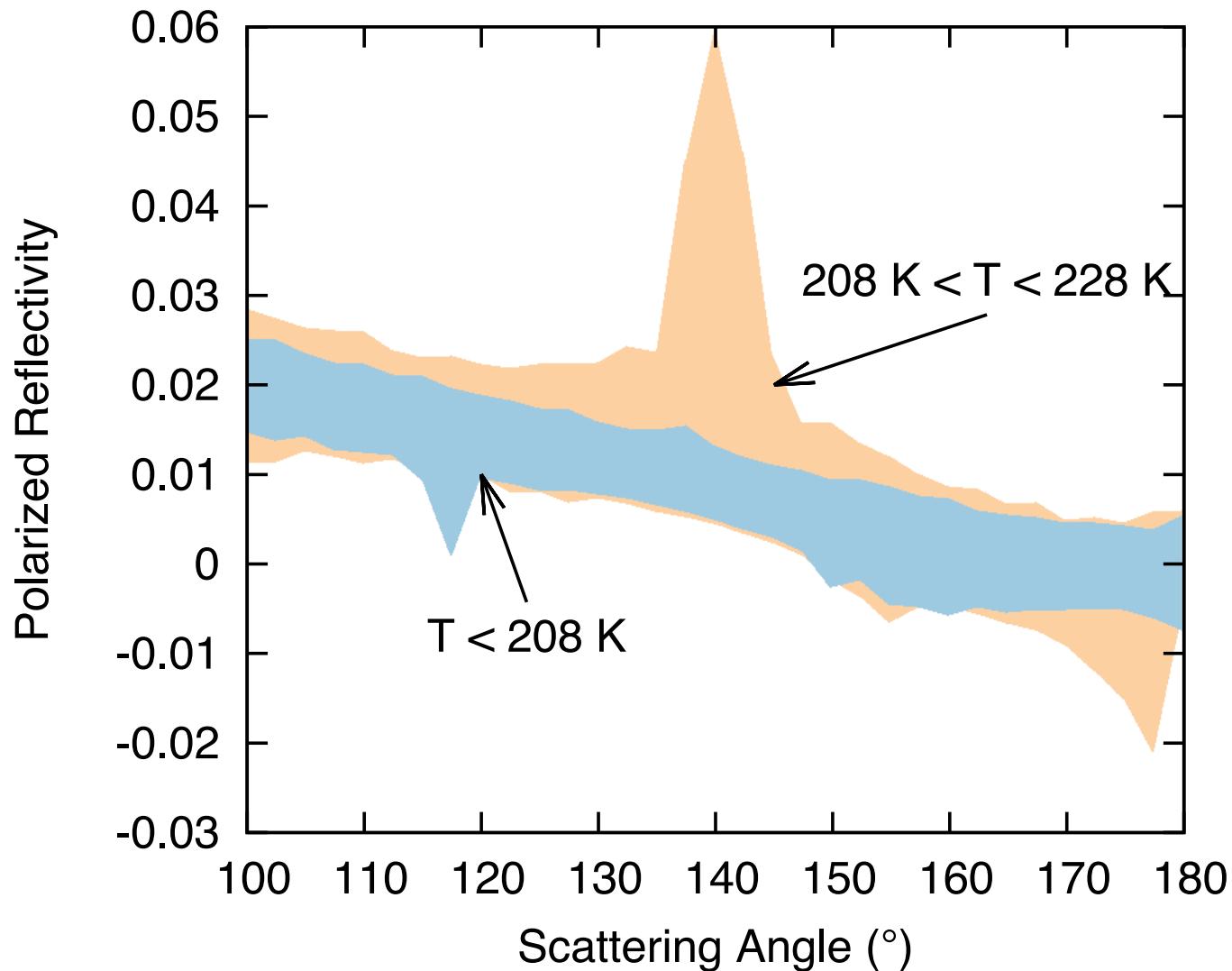
Consistency between solar-band and IR-band retrievals



Polarized Reflectivity: THM vs. POLDER



Observation Density Envelopes



Computation of Band-averaged bulk scattering properties

Effective diameter $D_{eff} = \frac{3}{2} \frac{\sum_{h=1}^M \left[\int_{D_{min}}^{D_{max}} V_h(D) f_h(D) n(D) dD \right]}{\sum_{h=1}^M \left[\int_{D_{min}}^{D_{max}} A_h(D) f_h(D) n(D) dD \right]}$

Scattering cross section

$$\bar{\sigma}_{sca} = \frac{\int_{\lambda_{min}}^{\lambda_{max}} \int_{D_{min}}^{D_{max}} \sum_{h=1}^M [\sigma_{sca,h}(D, \lambda) f_h(D)] S(\lambda) n(D) dD d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} \int_{D_{min}}^{D_{max}} \sum_{h=1}^M [f_h(D)] S(\lambda) n(D) dD d\lambda}$$

Extinction cross section

$$\bar{\sigma}_{ext} = \frac{\int_{\lambda_{min}}^{\lambda_{max}} \int_{D_{min}}^{D_{max}} \sum_{h=1}^M [\sigma_{ext,h}(D, \lambda) f_h(D)] S(\lambda) n(D) dD d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} \int_{D_{min}}^{D_{max}} \sum_{h=1}^M [f_h(D)] S(\lambda) n(D) dD d\lambda}$$

Asymmetry factor

$$g = \frac{\int_{\lambda_{min}}^{\lambda_{max}} \int_{D_{min}}^{D_{max}} \sum_{h=1}^M [g_h(D, \lambda) \sigma_{sca,h}(D, \lambda) f_h(D)] S(\lambda) n(D) dD d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} \int_{D_{min}}^{D_{max}} \sum_{h=1}^M [\sigma_{sca,h}(D, \lambda) f_h(D)] S(\lambda) n(D) dD d\lambda}$$

Single-scattering albedo

$$\bar{\omega}(\lambda) = \frac{\bar{\sigma}_{sca}(\lambda)}{\bar{\sigma}_{ext}(\lambda)}$$

Gamma distribution

$$n(D) = N_0 D^{(1-3v_{eff})/v_{eff}} \exp(-\frac{D}{D_{eff} v_{eff}})$$

Ice water content

$$IWC = \rho_{ice} \sum_{h=1}^M \left[\int_{D_{min}}^{D_{max}} V_h(D) f_h(D) n(D) dD \right]$$

Bulk scattering properties parameterized as functions of effective diameter:

$$\langle \frac{\beta_e}{IWC} \rangle = \frac{a_0 + a_1 D_{eff}^{-1}}{1 + a_2 D_{eff}^{-1} + a_3 D_{eff}^{-2}},$$

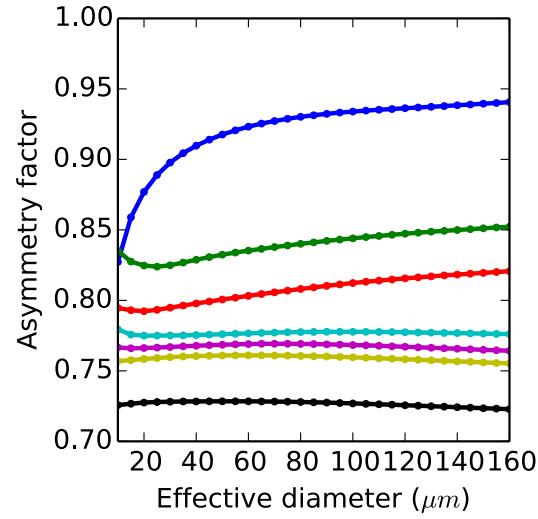
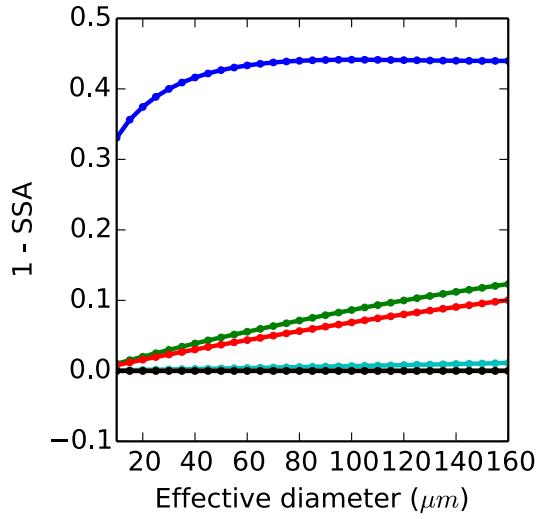
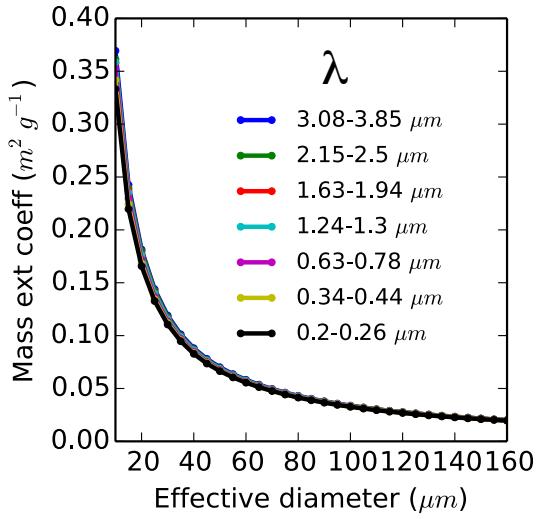
$$\langle \frac{\beta_a}{IWC} \rangle = \frac{b_0 + b_1 D_{eff}^{-1}}{1 + b_2 D_{eff}^{-1} + b_3 D_{eff}^{-2}},$$

$$1 - \langle \bar{\omega} \rangle = \sum_{n=0}^{n=4} c_n D_{eff}^n,$$

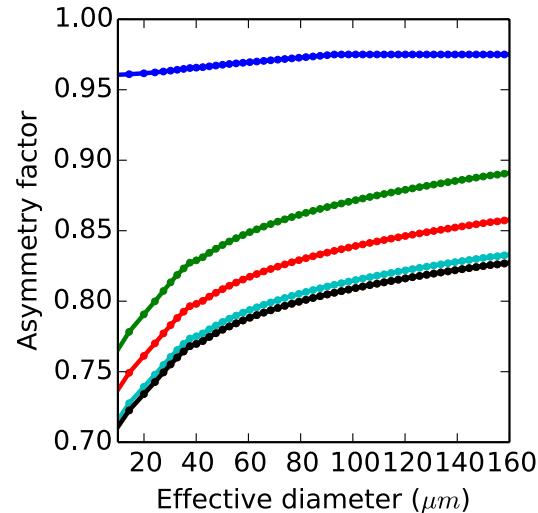
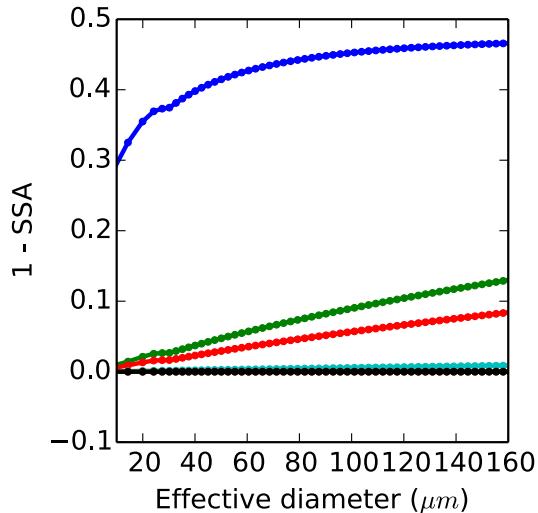
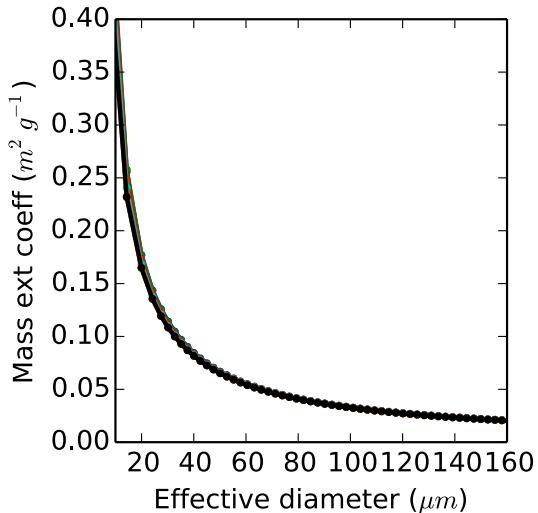
$$\langle g \rangle = \sum_{n=0}^{n=4} d_n D_{eff}^n,$$

Band-averaged ice cloud bulk optical properties: two-habit model versus CAM5

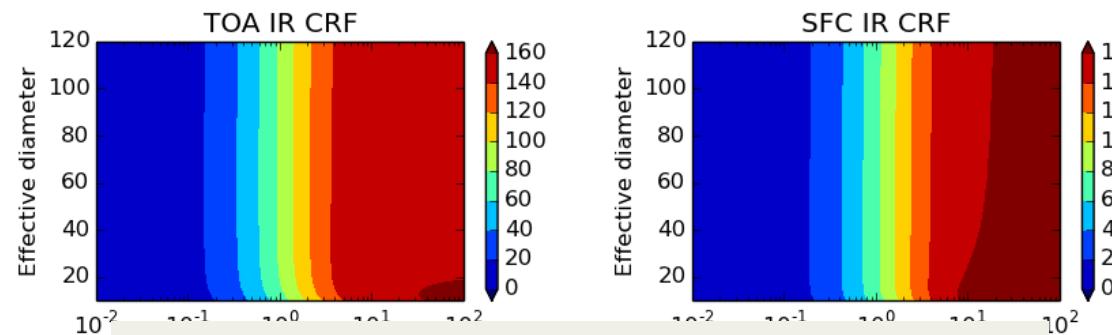
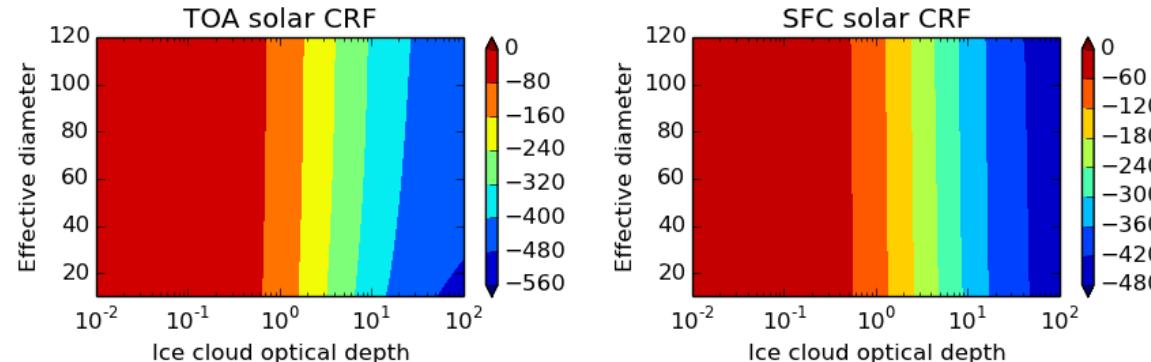
Two-habit



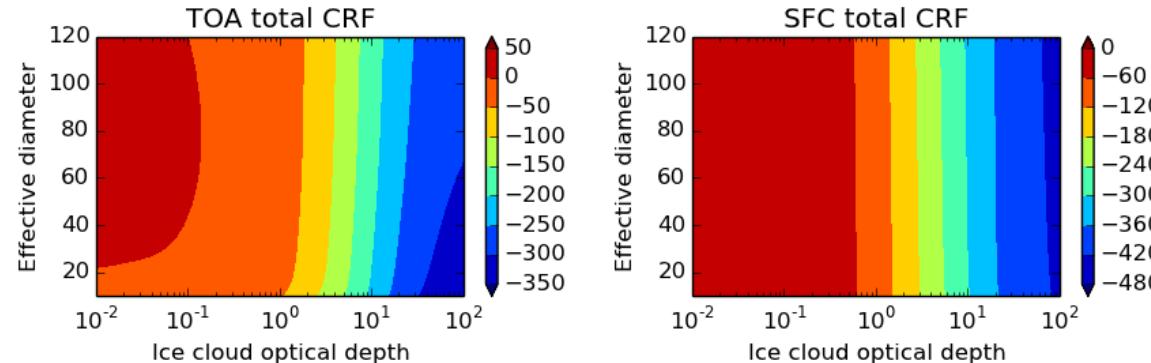
CAM5



Ice cloud radiative forcing at TOA and surface as function of THM effective diameter and optical thickness, SZA = 60°



Minimal Dependence on De



Comparison of CERES observations and simulations using Fu-Liou RTM

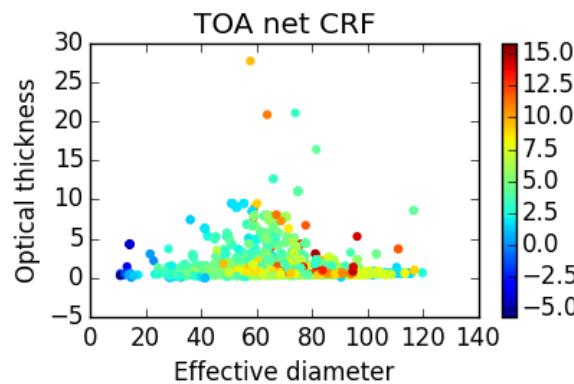
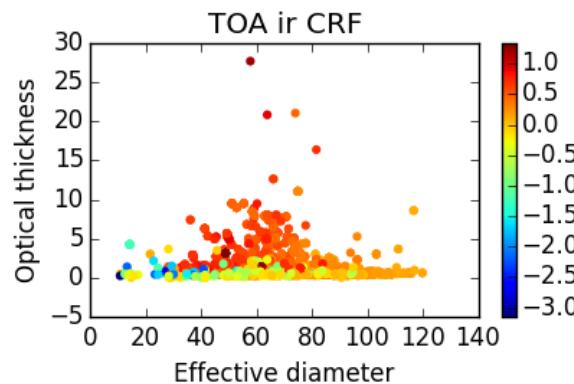
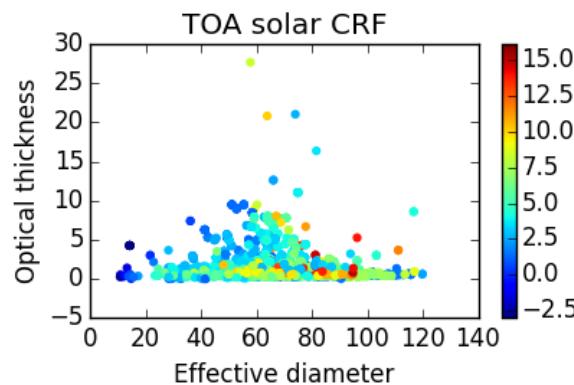
- CERES data:
 - SSF level-3 $1^\circ \times 1^\circ$ daily observations containing cloud information (cloud phase, optical thickness, cloud fraction, effective diameter, etc.)
 - SW and LW flux at the TOA under clear-sky and cloudy-sky.
- Simulations:
 - MERRA reanalysis daily atmospheric profiles are used;
 - Fu-Liou RTM is used for two cases:
 - **Default:** Fu-Liou RTM with SCM ice optics parameterization
 - **Two-habit model:** Fu-Liou RTM with new THM ice optics parameterization
- Data time range: January, April, July, and October 2010

Definition: CRF at TOA = TOA cloudy-sky flux – TOA clear-sky flux

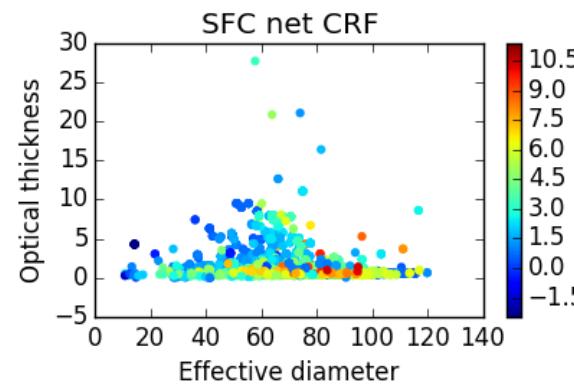
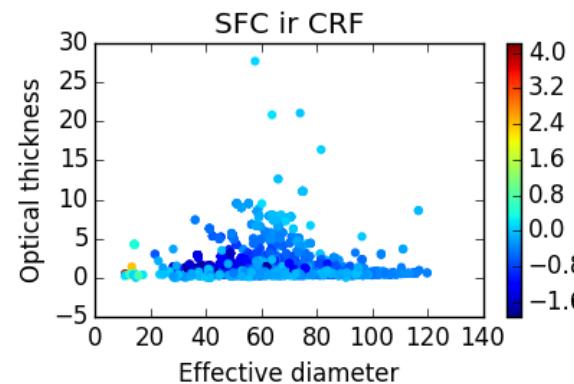
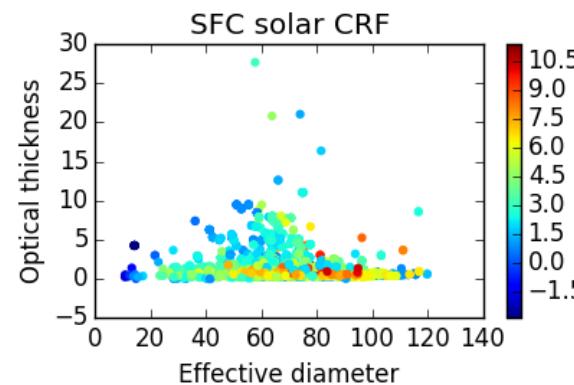
Methodology

- Use grid points with only ice clouds from CERES SSF
- Select corresponding atmospheric profiles from MERRA
- Determine cloud level from CERES cloud effective pressure
- Select necessary cloud parameters for RTM simulations: cloud fraction, cloud optical thickness, D_e , etc.;
- Carry out Fu-Liou RTM simulation for clear-sky, cloudy-sky with SCM, and cloudy-sky with THM
- Calculate cloudy-sky TOA radiative flux and ice cloud radiative forcing. Compare simulations with CERES observations.

Top of the atmosphere



Surface

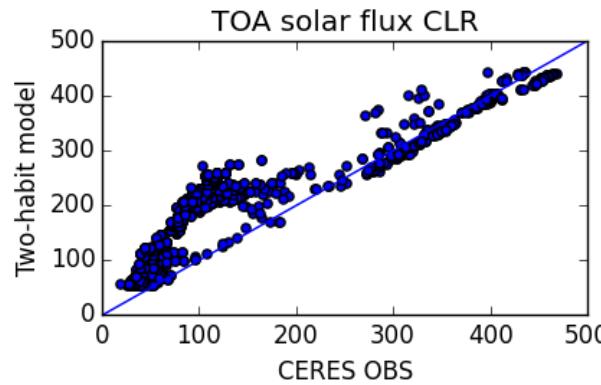


CRFs: THM minus SCM

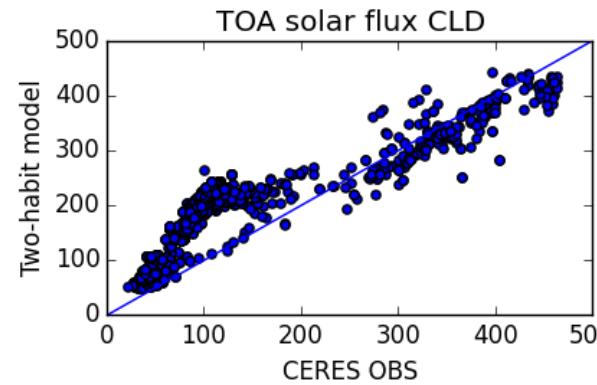
- THM has larger solar CRF than SCM.
- THM LW CRF similar to SCM, but slightly smaller
- Net forcing is several Wm⁻² larger for THM

Unit: W/m²

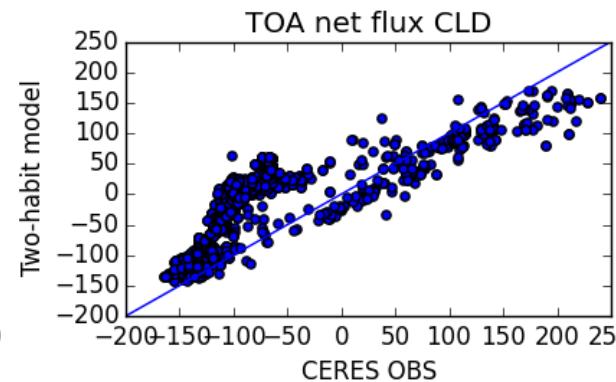
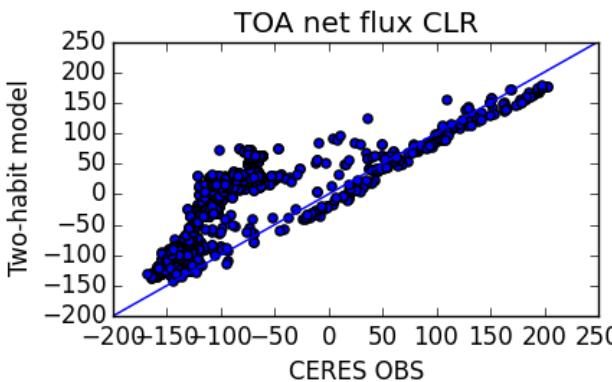
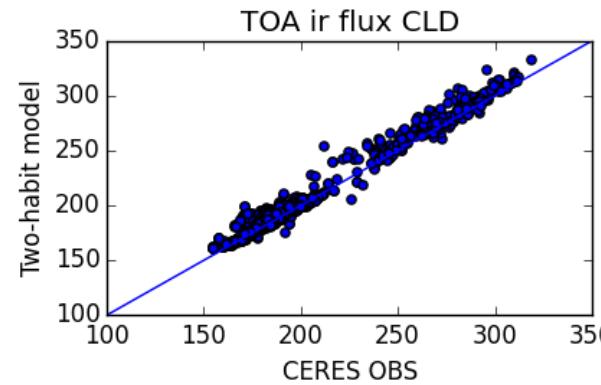
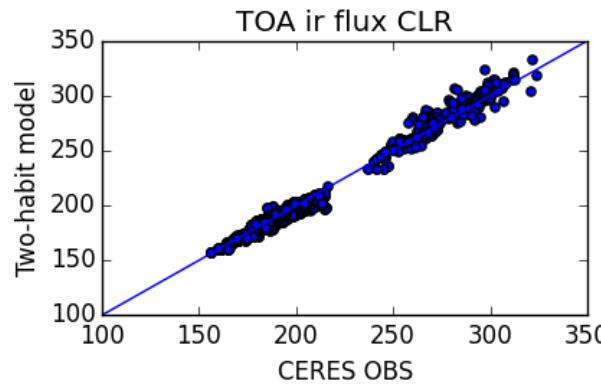
Clear-sky



Cloudy-sky



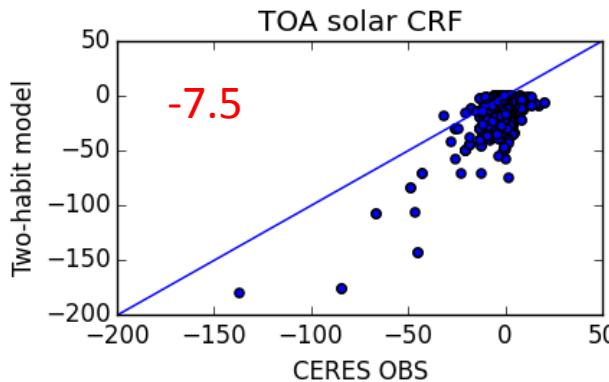
**TOA FLUX
THM vs CERES
preliminary results**



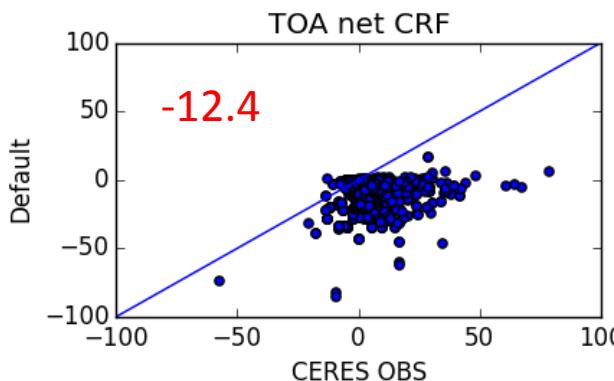
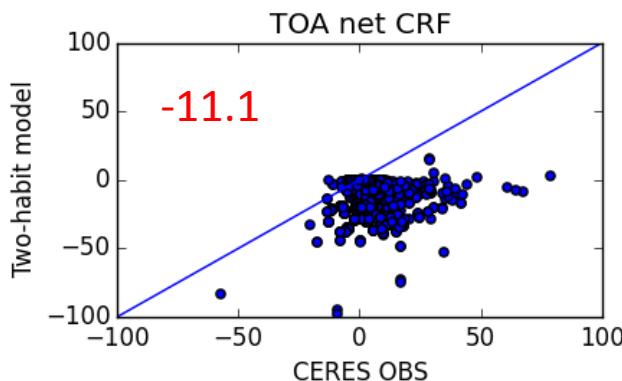
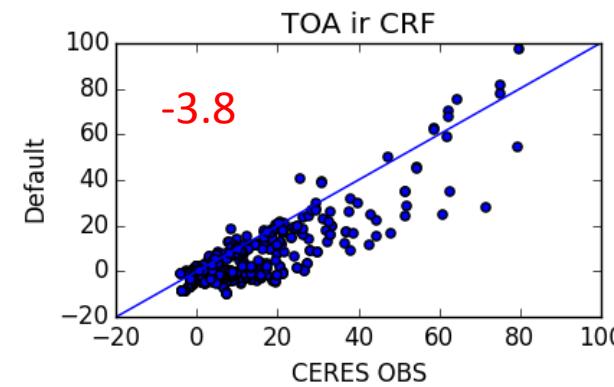
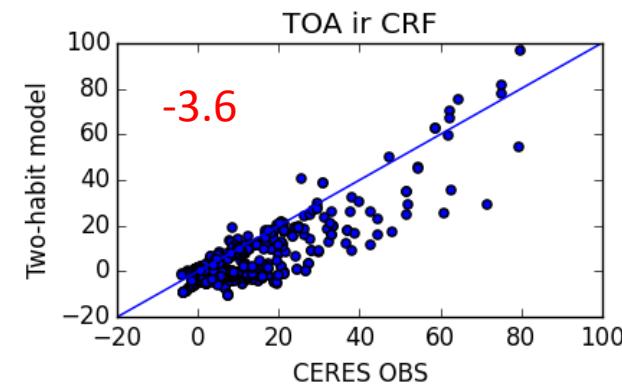
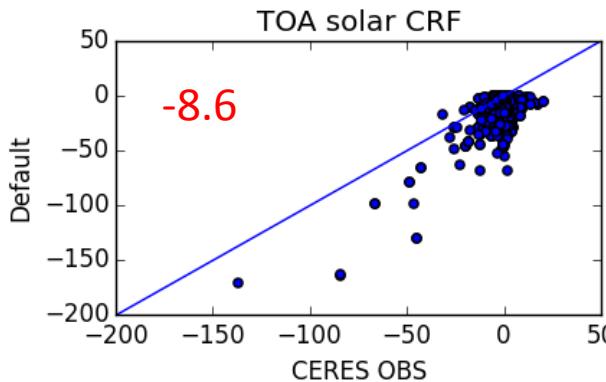
Unit: W/m^2

- Discrepancies in SW is likely due to uncertainty in surface albedo
- Observation and simulation are similar in the case of IR flux.

Two-habit model vs CERES



Default vs CERES



Unit: W/m^2

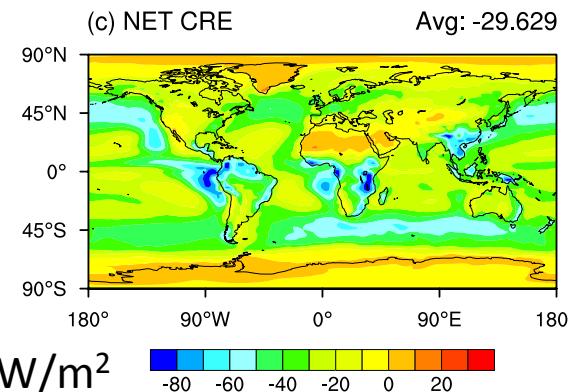
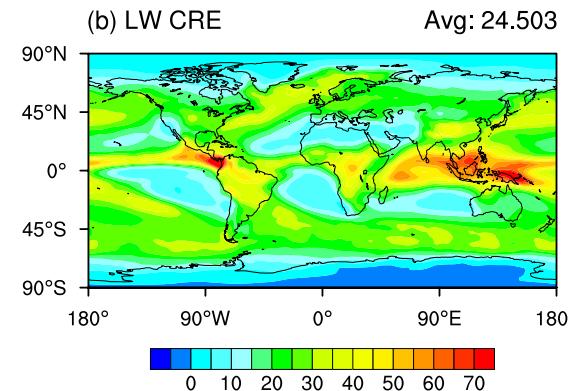
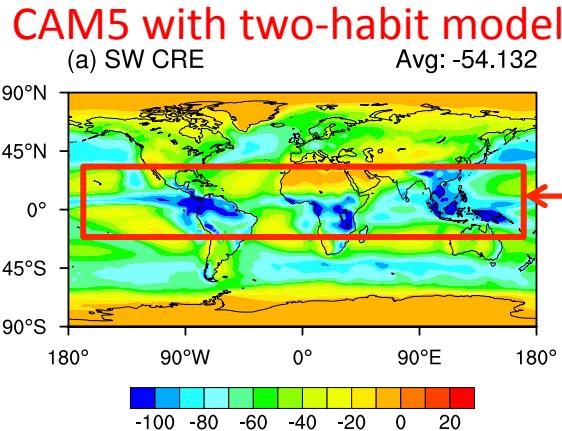
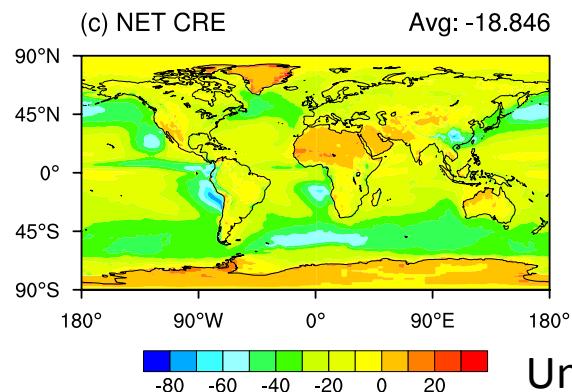
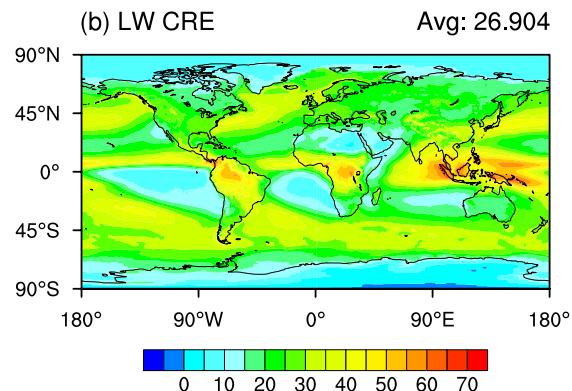
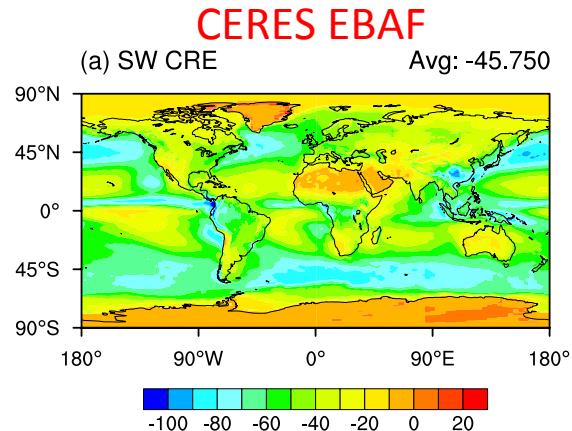
TOA CRF Simulation vs CERES

Preliminary results

- Only negative SWC RF is simulated, CERES shows both positive and negative CRF
- Net CRF is seldom positive in the simulation, but again both positive & negative in CERES;
- CERES solar/IR CRF may have uncertainties by themselves;

Red number panel shows the average difference:
 $\text{Simulation} - \text{CERES}$

Cloud radiative forcing: observation vs simulation



deep convection
microphysics
parameterization
problem

Conclusions

- Two-habit ice cloud optics parameterization scheme is developed and implemented in the Fu-liou RTM.
- Preliminary results show good agreement between CERES satellite observation of radiative flux at the top of the atmosphere (TOA) under clear-sky and ice cloudy-sky.
- Longwave ice cloud radiative forcing is well simulated by Fu-liou RTM with two-habit ice optics. However, shortwave radiative forcing simulations have some problems
- GCM simulation with two-habit ice optics also shows some improvements in the global longwave cloud forcing while shortwave forcing improvement is difficult to discern because of large biases due to convective clouds in the tropics.

Future work

- Improve the ice cloud radiation simulation by consistently representing ice microphysical and optical properties in the model.
- Data from several field campaigns are used and we found a new IWC-Deff relationship that depends on the cloud temperature. This new IWC-Deff relationship may further improve the specification of ice cloud effective particle size.
- Ground-based measurements at ARM sites will be used to test the two-habit model.